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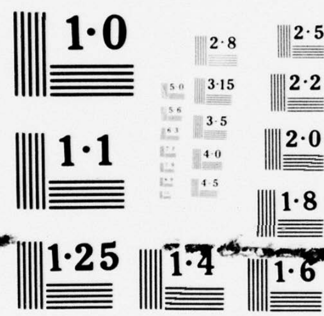

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DEFENSE SYSTEMS MANAGEMENT SCHOOL

STUDY TITLE: Improving Operational Readiness Through Increased Reliability and Maintainability.

STUDY PROBLEM/QUESTION: To assess the method used by the Naval Material Command in determining where to invest in increased reliability and maintainability.

STUDY REPORT ABSTRACT: The Naval Material Command, through the mechanism of the Detection Action Response Technique (DART) program, selects equipment in order of the problems each is observed causing in the fleet and invests an amount of money based on certain specific improvements estimated to be achievable. Problem equipments are ranked by a composite frequency of occurrence system weighted arbitrarily. The system works down the list until all available funds are expended. This system can be improved by better relating the impact of poor reliability and maintainability to the loss of operational readiness caused thereby.

KEY WORDS: RESOURCES READINESS OPERATIONAL READINESS REPORTS AND REPORTING DATA COLLECTION MATERIEL DESIGN AND DEVELOPMENT MTBF MAINTAINABILITY RELIABILITY INFORMATION SYSTEMS MAINTENANCE 3 M MEAN TIME TO REPAIR

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IMPROVING OPERATIONAL READINESS
THROUGH INCREASED
RELIABILITY AND MAINTAINABILITY
STUDY REPORT
PMC 73-2

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KENNEY

IMPROVING OPERATIONAL READINESS
THROUGH INCREASED
RELIABILITY AND MAINTAINABILITY

An Executive Summary
of a
Study Report
by

L. H. Kenney
LCDR USN

December 1973

Defense Systems Management School
Program Management Course
Class 73-2
Fort Belvoir, Virginia 22060

EXECUTIVE SUMMARY

The Navy, in its concern to improve its operational readiness by improving equipment reliability and maintainability has developed a system for identifying which equipments are the most deficient in these parameters. The operators file casualty reports and the operating engineers file maintenance data reports. Each of these reports has implications for the measurement of the reliability and maintainability of the equipments reported. The casualty report describes in detail the relationship between the failure reported therein and operational readiness.

Significant numbers of failures in one equipment or unacceptable reductions in operational readiness caused by one equipment pose a classical capital budgeting problem for the Naval Material Command (NMC); i.e., how much improvement in reliability and maintainability is required to reach acceptable values? What is the cost of achieving various improved values? And what is the appropriate amount of resources to invest in achieving these values?

Historically, the NMC has been able to answer the first two questions satisfactorily. The answer to the third is hampered by the difficulty in correctly modelling the relationship between operational readiness and failure of specific equipments. The casualty report assesses this relationship satisfactorily for operational purposes, which are these reports primary objectives, but the NMC use of this report for providing information to an economic, cost-comparison decision is subject to improvement.

The NMC allocates funding for equipment improvement programs on the basis of a simplified weighting of the aggregate of casualty reports and maintenance data reports allocating to the equipment which appears most troublesome first, then to the second-most troublesome equipment and so on until funds are no longer available. This system of allocating funds avoids making decisions on the basis of relative costs, hence the need for a credible cost relationship is downgraded.

A credible cost relationship requires that all pertinent cost be commensurable; i.e., capable of being compared one against the other. Costs can achieve "commensurability" either by being convertible to a common cost unit or by the use of judgement. In order for this judgement to contribute to a credible relationship, the individual exercising it must intuitively understand the cost units involved and be accountable for the costs inherent in the exercise of his judgement.

Application of this use of judgement to the NMC's development investment decision requires that the conversion of operational cost units to units of investment cost, such as funds and time, be done by the operational forces rather than the NMC. This is not to say that there are not individuals in the NMC who understand operational readiness. But this assertion does imply that the required understanding is not prevalent at the origins of these investment decisions. The operational commander is in the best position to convert operational readiness cost units to units of investment cost.

IMPROVING OPERATIONAL READINESS
THROUGH INCREASED
RELIABILITY AND MAINTAINABILITY

STUDY REPORT

Presented to the Faculty

of the

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in Partial Fulfillment of the

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Class 73-2

by

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December 1973

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IMPROVING OPERATIONAL READINESS
THROUGH INCREASED
RELIABILITY AND MAINTAINABILITY*

CHAPTER I

How the Impact of Reliability and Maintainability Deficiencies is Observed and Evaluated

A. The Operator's View. In the Navy the term "operational readiness" represents a figure of merit which the operational forces rely on heavily to measure their effectiveness. They have several well-defined precise means of calculating operational readiness and, for their purposes, effective means of tracing operational readiness deficiencies to their causes.[1] A significant portion of these causes originate in equipment which fails too frequently or is too difficult to restore to satisfactory operation because of problems in diagnosing and repairing trouble or inadequate spare parts and tools.

B. The Naval Material Command (NMC) Role. These equipment problems are the concern of the NMC. The NMC has applied the commonly understood concepts of reliability and maintainability to provide a figure of merit

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*ABSTAINER

This study represents the views, conclusions and recommendations of the author and does not necessarily reflect the official opinion of the Defense Systems Management School nor the Department of Defense.

1. The reader may refer to any administrative commander's (type commander, squadron commander, et al) training manual to observe the exhaustive rating systems prescribed for operational readiness measurement and the documentation required by observed deficiencies to verify this statement.

for measuring effectiveness in handling these problems. By meticulous data collection from existing reporting systems, the NMC is able to maintain records showing problems in the reliability and maintainability of shipboard equipments.

This paper intends to demonstrate to students of material management that the two figures of merit are commensurable, but that the relationship is not obvious, and that the NMC's model for this relationship, although adequate, is subject to some improvement.

C. Failure Occurance. Reliability can be quantified by determination of mean-time-between-failure (MTBF) or mean-time-between-maintenance-action (MTBMA)[2] and mean-time-to-repair (MTTR). Time between-failure is all time an equipment is operational within design limits and time-to repair is the converse.[3]

The NMC relies on the prescribed Casualty Reporting[4] System and the Maintenance Data Collection System[5] to provide information on failure occurance. Both systems require that reports specifically state whether an equipment reported on is operating within design limits or not.

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2. The two terms are not synonomous. Their use within the NMC varies from one systems command to another. The latter term includes all corrective maintenance actions; the former does not. The way they are used as an overall figure of merit makes insignificant, for the purpose of this paper, the differences in definition.

3. This criterion is not officially prescribed, but is in general used by the relatively few individuals who calculate these figures for the NMC.

4. Naval Weapons Information Procedures Operational Reports, (NWIP-10-D) Chief of Naval Operations 1971.

5. Navy 3-M Maintenance Manual (OPNAV 43P-2) Chief of Naval Operations 1970.

D. <u>The Casualty Reporting System</u>. The most visible reporting system providing failure information is the casualty reporting system. This system's basic function is to transmit information from the operational unit commander up the operational chain of command describing those casualties which impair his ability to carry out assigned missions. The mission involved may be a permanent mission dependent only on the unit's configuration or a temporary mission assigned by an operational commander or assumed by the unit commander. The casualty report contains both coded and uncoded information describing the casualty. The procedure prescribed for submitting casualty reports requires that material casualties be described in two equipment-coding systems and in plain language such that assessments can be made up the chain of command of the need for an immediate response. In addition, casualty reports are required to be transmitted to various activities within the NMC.[6] From these reports and their updates NMC is able to keep a record of what equipments fail, how long repairs take, and to some extent, what problems are causing the failures and what problems are encountered in making repairs. See figure 1 for the flow of casualty reports.

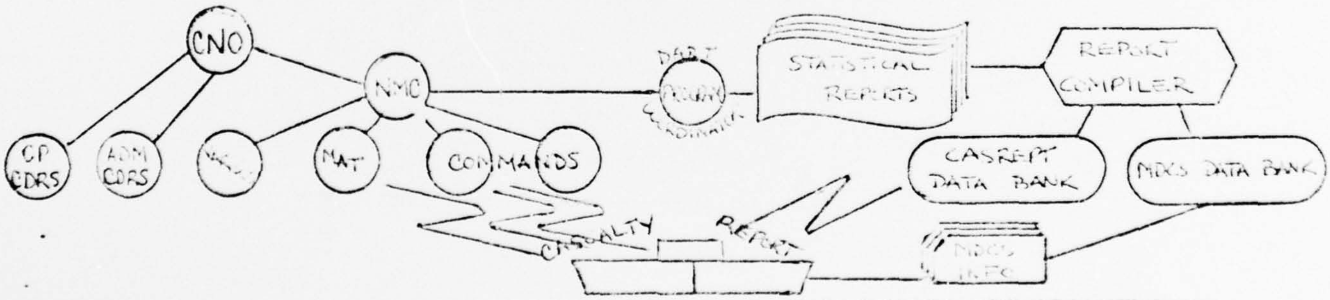

Figure 1. Flow of Casualty and 3M Reports.

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6. NWIP-10-1D. The same report format, with different coding systems, is prescribed for personnel casualties.

E. The Maintenance Data Collection System (MDCS). Because a casualty report serves first on operational need, the NMC relies on the MDCS for a supplement in providing more specific and more maintenance-oriented information concerning equipment failure. This system requires a report every time any maintenance action is performed.[7] The report attempts to describe in detail, by means of several codes, the nature of the maintenance action and if a failure has occurred. See figure 1 for the flow of MDCS reports. The MDCS has operated since inception under problems rooted in oversophistication and poor visibility of its benefits. Nonetheless when used in conjunction with the Casualty Reporting System, the MDCS provides useful supplementary information and correlation. Of particular interest is the indication MDCS gives as to whether or not a failure has occured and whether or not the problem is related to the design of the equipment. The casualty report tends to describe symptomatic behavior while failing to pinpoint exact causes. For example, often the equipment cited in the casualty report has not failed, but is the equipment wherein the loss of operational capability first appears. The failure may have occured in another part of the system. The MDCS helps solve this problem by treating the failure as a requirement for maintenance, rather than a loss in operational capability. The MDCS, by requiring reports on most maintenance actions, documents many failures which for operational reasons, do not require casualty reports.

F. Operational Conditions of Readiness. The Casualty Reporting System divides all casualties into four gross categories.[8] The category a given

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7. OPNAV 43P-2. A few equipments have been exempted from 3M reporting requirements since issuance of the manual.

8. NWIP 10-1D.

casualty falls into depends on its degrading effect on operational readiness. The category titles and description of the degrading effects are:

C-4 - causes a major degradation in more than one primary mission area.

C-3 - causes a major degradation in one mission area.

C-2 - causes minor degradations in a primary mission area.

C-1 - causes degradation only in secondary mission areas.[9]

A failure not falling within categories C-2, C-3, or C-4 does not require a report. The term C-1 normally refers to a ship or other operational unit and indicates the operational unit is one hundred per cent operationally ready.

The general nature of the criteria for classifying casualties by condition of readiness allows considerable subjectivity and interpretive license on the part of the unit commander on filing his casualty report. For instance, examples of primary mission areas permanently assigned a unit are anti-submarine warefare and shore bombardment. Few equipments on ships are wholly dedicated to one of these mission areas. Yet a failure in many equipments can be adjudged to cause a major degredation in one mission area and minor degradations in others. What constitutes a major degradation and what constitutes a minor degradation are judgements largely at the discretion of the unit commander. Also, because a unit's primary mission areas are not limited to those resulting from unit configuration, but subject to additions caused by operational requirements, the unit commander can infer that under a given set of

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9. NWIP 10-1D

conditions he has a primary mission that is not included in his normal assignment or that another set of conditions has relegated what is normally a primary mission to a secondary status.

G. The Material Condition Index (MCI). The NMC has two responsibilities related to casualty reports. First, as a purveyor of maintenance service, the NMC must hold ready the resources required to provide corrective maintenance, when tasked by the operational commander. More important, the NMC must seek the prevention of casualties through improved equipment. A major NMC dilemma, therefore is where to apply limited resources in order to be most productive in attacking the casualty problem.

The MCI provides a ranking of equipments in order of the readiness degradation the operational commanders ascribe to them. The MCI for a given equipment is calculated according to the following formula:

$$MCI = (C_4 + .5C_3 + .1C_2) \times TD/C$$

Where C = Tot nr of casualty rpts filed for a given eqmt class'd C-4

C4 = Tot nr of casualty rpts filed for a given eqmt class'd C-4

C3 - Tot nr of casualty rpts filed for a given eqmt class'd C-3

C2 - Tot nr of casualty rpts filed for a given eqmt class'd C-2

TD = The total time in weeks between casualty and repair for all casualties filed for a given equipment.

When an equipment achieves a relatively high MCI, the inference is clear that operational units consider the equipment a problem. The NMC uses the MCI to suggest equipment wherein improved reliability and maintainability will significantly improve overall Navy operational readiness.

H. The MDCS Model. The MDCS system also provides a ranking of equipments in accordance with the maintenance problem each presents. Eight statistics emerge from the MDCS data bank which vary directly with the size of the maintenance problem of a particular equipment. The totals of these statistics are added, the largest sum indicating the equipment with the largest problem.

CHAPTER II

The Detection Action Response Technique (DART) Program

A. DART Purpose. The DART program, is a NMC program funded to investigate, diagnose, solve and report on those equipments which appear to cause the largest deficiencies in operational readiness. The NMC initiated the DART program in 1971. Over thirty equipment problem solving efforts have been funded from DART. Six problems are considered solved and the remaining efforts are still in progress. Many problems have been diagnosed to be rooted in inadequate training, technical manuals or available maintenance facilities, but nearly all have some basis in a design or manufacture lacking in reliability and maintainability. Some arise nearly entirely from these latter causes.

B. Selection of DART Equipments. The selection of equipments for the DART program is based on the ranking systems described in I-G and -H above. The most troublesome equipments can be identified without the benefit of these ranking systems, but the objective of optimizing the use of limited funds requires that only those equipments through which the greatest improvement in overall operational readiness can be achieved receive DART status and that a sharp line be drawn between these equipments and all other troublesome equipments. The ranking systems draw this line in the following manner: Every equipment on which reports are received through both the Casualty Reporting System and the MDCS is assigned a rank as described in I-G and -H above. The rank the equip-

ment receives in MCI is added to the rank received in the MDCS model and for each equipment the two ranks summed. A composite rank emerges therefrom based on these sums. Lowest sum indicates most troublesome equipment (composite rank #1). Generally, a high composite rank qualifies an equipment for a DART investment. Investment costs also affect this determination. This effect will be discussed with other cost factors in the reliability and maintainability problem.

C. Forced Draft Blowers - an example.[10] There are two forced draft blowers installed for every water-tube boiler in the Navy for a total equipment population of 1542. One might expect an equipment genre with such a high population, which is necessary to every facet of a ship's operation and which runs under severe stress in an inhospitable environment, to have a high state of failure without indicating negligence in equipment design or manufacture. The same circumstances, however, make relatively valuable small reductions in failure rate or total time out of commission. Therefore forced-draft-blower designs and manufacture are given the extra scrutiny the DART program affords. There is no lack of ideas within the NMC technical community on ways to improve the reliability and maintainability of forced draft blowers or equipments of a similar degree of sophistication. The weak points in this type of equipment are fairly well known. Visibility of the problems and the ensuing funding are the ingredients lacking for the pursuit of solutions. Therefore, given the determination that forced draft

10. A forced draft blower is a high speed rotary fan which forces large volumes of air at high overpressures into the combustion boxes of marine boilers.

blower failures are creating unacceptable degredations in operational readiness represented by a high MCI/MDCS composite rating NMC has only one short step to take to include it in the DART program.

CHAPTER III

The Cost Resolution

Costs of Investing

	Dollars	Time	Other
Diagnose	Yes	Yes	
Redesign	Yes	Yes	
Procure	Yes	Yes	
Retrofit	Yes	Yes	Yes [1]

Cost of Failing to Invest

	Dollars	Time	Other
Maintenance	Yes	Yes	
Substitution	Yes	Yes	
Op'l Read.			Yes [2]

[1] The requirement that a portion of the operational forces be made unavailable for operational use for a discrete time.

[2] The risk of damage resulting from mission failure inflicted by self, enemy, or external natural causes.

A. The Cost Question. The decision to pursue improved reliability and maintainability in a given equipment is the action dictated by the conclusion that the savings estimated from this improvement is greater than the estimated cost of achieving it. Under the DART program the conclusion is that the gain is greater for equipments funded by DART than for all other equipments.

B. Estimating Investment Costs. There are four elements in the cost of investing in improved reliability and maintainability, problem diagnosis and analysis, component redesign, component procurement and retrofit of installed equipments. (See Figure 2). The normal procedures for estimating and accounting for these costs for the DART program are described in the following paragraphs.

1. Diagnosis. Technically competent people at the Naval Ships Engineering Center (VAVSEC) are issued job orders to investigate and analyze the design and manufacturing deficiencies and prescribe corrective action.[11] The cost of these job orders is the most difficult element of the improvement program to estimate. Although a ceiling on expenditures is normally stipulated on this type of job order, the amount is heavily influenced by the manpower available to work the problem during a given fiscal period and only nominally based on an analysis of the task. However, the effect of the uncertainty in this element on estimating the cost of the entire program is attenuated by the normal size of diagnosis cost compared to other elements.

2. Redesign. Redesign costs are estimated in detail during diagnosis and included in the DART budget for each equipment.

3. Procurement. Procurement costs are estimated from problem analysis and contractor quotes. Experience has shown the estimating of these and the redesign costs to be accurate to within tolerance made insignificant by uncertainty in the costs against which they must be balanced.

4. Retrofit. Again these costs are estimated after a detailed analysis of the component tanks. There is an additional and less easily estimatable cost in the retrofit element. All elements use time and money, but time for retrofit represents a loss to the operating forces of the availability of the unit being retrofitted. The effect of this

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11. Job orders here are fund citations specifing a given amount of effort based on informal negotiation between program coordinators and supervisory engineers.

difficulty on cost can be avoided, however, by accomplishing the retrofit during periods when the unit is normally scheduled for maintenance. Implicit in this means of avoiding the difficulty is the assumption that no improvement program is urgent enough to require a disruption of a ship's operating schedule.

These elements are divisions postulated by this writer for convenience. The aggregate, however, resembles strongly the standard investment cost as described by Baumol in his analysis of the decision to repair.[12]

Not all equipment problems can be laid wholly at the door of deficiencies in reliability and maintainability. Poor (or poorly promulgated) maintenance and operational procedures and personnel training deficiencies cause equipment problems. DART encompasses equipment problems of these types. However estimating costs of the fixes required by these non-design, non manufacture problems will not be discussed here.

C. Estimating the Costs of Not Investing. There are three categories of costs that arise from all deficiencies in reliability and maintainability. (See Figure 2).

1. Maintenance. The first category is actual maintenance, i.e. the manhours and materiel costs of performing the additional maintenance. For a given set of reliability and maintainability data these costs can be calculated with a reasonable degree of accuracy. Materiel costs subdivided into procurement/manufacture, storage, handling and

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12. William J. Baumol, Economic Theory and Operations Analysis, Chapter 19 (Prentice-Hall) Englewood Cliffs New Jersey 1972.

shipment. Manhour costs are only slighly more uncertain in that most maintenance on Navy equipment is done by a salaried or hourly-rate employees, for which a significant amount of arbitrary prorating must be done to assign a dollar value to manhours spent in maintenance activity. All the difficulties in determining an overhead base are present, plus in the case of military personnel, the effect of military duties (watchstanding etc.) and variance in the duration of the normal workday education complicate the prorating procedure. The shipboard environment is especially unique, for the value of a maintenance manhour spent while a ship is operating at sea is difficult to compare to the value of the equivalent manhour spent while the ship is in port. Nonetheless, by a process of averaging skill levels and the standard shipboard workday a manhour cost figure in dollars can be calculated and compared with confidence to other costs measured in dollars.

2. Substitution. More difficult to measure is the second category of reliability/maintainability produced costs. These are the costs incurred by taking action to compensate for a system down for maintenance. These costs are separated not because they are difficulty to convert to dollars. Most compensating actions equate to the expenditure of more manhours and material. The difficulty in predicting these costs for a given equipment arises from the dependency of these costs on circumstances unrelated to the equipment at fault. Referring back to the forced draft blower problem of II-C, a ship lacking one force draft blower may necessitate the putting to sea

of an additional ship, a costly maneuver. Or simply operating another of the ships forced draft blowers beyond its prescribed preventive maintenance check may prove sufficient.

3. Reduced Readiness. Most difficult to measure is the third category of costs, those of operating in a reduced condition of readiness; i.e. operating without taking compensating action. These costs are measured in the increased risk of damage occuring either to the unit itself or to whatever entity it is the units mission to protect. The risk involves damage expected from the failed equipment, other natural causes or the enemy. Converting damage risk to a measurable quantity with commonly understood implication requires much analysis.

D. The Commensurability of Costs. Implicit in the categorizing of costs in C. above is the thesis that costs need not be identified in dollars or confined to quantities of any form of resource. In the most general case costs related to any action (or inaction) are the alternative uses of the resources expended; i.e., the "opportunity cost concept."[13] Costs may be identified in such vague terms as "good will" or valued in such invaluable units as human lives and limbs. Costs expressed in terms of money, man-hours, or time acquire their commensurability from the existence of a common, precise understanding of the units involved. Costs expressed in less precise or commonly understood units acquire commensurability from the correlation between the identifier and payer.

In the most extreme case, a human life is an invaluable cost, unexpressable in any other unit to the person who will lose it. That same

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13. William Warren Hayes D.C.S. Managerial Economics. Ch 2, Business Publication. Austin, Texas 1969

human life is not easily valuable for individuals personally involved with its owner.

In the realm of equipment reliability and maintainability, for example, in the forced draft blower analysis, a cost of a forced draft blower is a knot (nautical mile per hour) for a given class ship. An engineer at NAVSEC may conclude on the basis of this estimate that one thousand weeks of forced draft blower down-time equates to a five-hundred knot-hour capability loss in the fleet, but his conclusion has little use as a justification for an investment of funds to lessen that downtime.[14] But if a ship's captain reports that a failure of one forced draft blower is preventing him from putting to sea; that is reducing his ship's speed to zero, that cost is a valid input to a justification for remedial action because the identifier of the cost is also paying it.[15] Senior individuals or inclusive organizations may incur a cost arising from this ship's loss of capability, but assuming reason prevails, the ship's captain's estimate of the cost is the relevant one for two reasons:

1. As this cost is transmitted it will be compared with alternatives. The alternative cost will be preferred whenever it is the lesser.

2. An effective senior will endeavor to make any loss in capability less to himself than to the responsible junior.

Similarily, if one-hundred ships each report that they are suffering a one-half knot loss in speed capability for a period of ten hours, each

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14. The capability of travelling at a speed one knot greater is not equal a navigational velocity one knot greater; therefore one knot-hour of capability is not equal to one nautical mile.

15. The likelihood of a forced draft blower casualty preventing a ship from putting to sea is very small, but not nil; for instance, if there are related casualties or repair facilities at hand.

ten hour period required to repair a forced draft blower there exists a five-hundred knot-hour (100 failures times ten hours x 1/2 knot 1 failure) capability loss in the fleet. This cost is a valid input to the preparation of a justification for the investment of funds.

An incurred cost cannot by itself constitute a justification for an investment. Only to the degree that past costs are related to the publication of future costs, should past costs be considered in determining the amount of investment justified.

CHAPTER IV

The DART Decision

A. Information required. The decision-maker in determining whether or not to invest DART funds in improving the reliability and maintainability of an equipment must obtain and compare several pieces of information. The relationship of dollars spent to improvement (increased M&BF, decreased MTTR) expected, the cost of individual failure and the relationship between the probable frequency of failure occurrence and equipment M&BF and MTTR. The value of increased reliability and maintainability can be estimated from the latter two and compared against the former. If all costs could be accurately estimated in dollars, no decision would be required. The program would operate automatically. The program would input funds available, select those equipments with the greatest difference between investment cost and estimated cost savings until all funds were programmed and display those equipments which fell on the borderline to determine if more funds should be sought. However, the conditions allowing automatic operation are highly unlikely. In fact, in this writer's opinion, the desire for automatic operation results in a tendency in the Navy for neglect of costs not readily expressible in dollars in making the DART investment decision. Fortunately, this tendency is more and more being successfully combatted, for as Chapter III showed, those other costs are real; they are significant; and in some cases make insignificant the costs readily expressible in dollars.

B. The Decision Origin. The decision-maker concerned with assigning equipments DART status is a somewhat elusive individual. He exists somewhere in the bowels of the Naval Ships System Command (NAVSHIPS) and his decisions originate like bubbles at the bottom of a pan of boiling water. Informal and formal inputs are coordinated here, and in this NAVSHIPS 0451 quantitative analysis is first applied specifically to the decision. The cost of improvement is estimated as described in III-B, but the converse costs are considered only as they are represented by the composite MCI/MDCS ranking. This office is limited in its appreciation of MCI by lack of experience with the ingredients which generate it. Here, therefore the MCI cannot be quantitatively factored into the decision. In practice this limitation is circumvented by the one-by-one priority listing. The top ranked equipment is selected and the total estimate of funds for it programmed. Then the second ranked equipment selected and so on until funds can no longer be obtained. The funds programmed for each is determined by the increase in reliability and maintainability desired for the individual equipment. No tradeoff analysis can be done to determine where the most benefits per dollar invested can be achieved given the subjectivity of the MCI. These deficiencies present problems, not in that they prevent recognition of which are the most troublesome equipments, but in that they prevent the predicting of quantitative outcomes from actions taken to make these equipments less troublesome.

C. Decision flow. Decisions originating in NAVSHIPS lack consideration of operational readiness factors. Before a final decision is made at Headquarters, NMC these factors may be considered. Supporting this possibility is the fact that between origination and finalization, each decision must receive approval from individuals who do have adequate awareness of the costs inherent in a high MCI. Decreasing this likelihood, however, is the sharply broadening responsibility of these individuals as the decision moves away from the DART program coordinators.

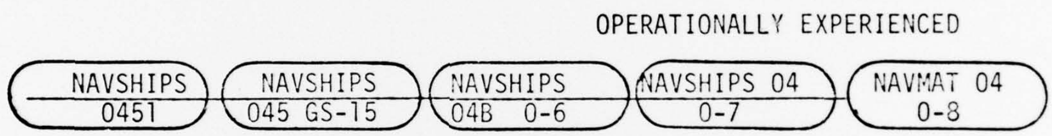

FIGURE 3 DART DECISION FLOW

CHAPTER V

Achieving A Better Decision Analysis

A. The Requirement. The increased recognition of costs, like increased MCI, which are difficult to measure in dollars has created a need for a rational method for comparing dollars and other costs. In advocating the use of quantitative methods in defense decision-making, Hitch and McKean assert that it is the role of "judgement" to compare costs which are "incommensurable".[16] The requirement for improving the investment decision analysis is to more precisely define the role of judgement.

B. The Criteria. The assertion that exercising of judgement allows one to select from "incommensurable" alternatives implies that the selection results from an intuitive quantification of these alternatives. The criteria for rational measurement of costs is therefore that the units of cost be commonly and precisely understood, e.g., dollars, manhours, or that the individual measuring intuitively, understand all units of cost involved, e.g., the cost of reduced speed capability caused by a forced draft blower casualty as discussed in III-D.

C. Finding Areas for Improvement. To find the extent to which the decision-maker can make his analysis more rational in the reliability and maintainability improvement problem, reexamine the two kinds of cost information available and used.

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16 Hitch and McKean, Elements of Defense Economics, Chapter VII, (ICAF), Washington, DC, 1967

1. The Investment Cost. Diagnosis, redesign, procurement and retrofit are the elements. Diagnosis is the only element whose cost is not accurately predictable as a function of performance improvement desired. Diagnosis produces a shopping list of possible improvements with predicted performance and cost effects. All elements are expressible in units of dollars and time, although time to redesign and procure is not directly equatable to time to retrofit as discussed in III-B-4.

2. The Cost of Not Investing. More maintenance, employment of additional equipments, and reduced operational readiness are the elements. The cost of more maintenance is predictable from existing MDCS data, which tabulates manhours and labor costs for maintenance on the unimproved equipment. These costs are commensurable. The cost of additional equipment employment and operational readiness reduction is represented by the MCI. The MCI sums the number of weeks that a loss of operational readiness is apparent and weighs this loss in accordance with the operational commander's appreciation of its seriousness. Subjectively incorporated in this assessment is the availability of resources other than maintenance capability which can be applied to compensate for this loss.

The decision-maker must weigh, therefore, am expenditure of funds for improvement against continued expenditure for high maintenance plus the acceptance of less operational availability. The former two can be adequately measured by anyone, but the latter only by someone capable of judging the cost of reduced operational readiness. Therefore, the most likely means for improving the decision analysis is to find a more universally understood unit for operational readiness.

D. Analysis Improvements. There is a wide range of alternatives for remedying this situation. At the opposite extreme from complete dependence on the MCI, instructions could be issued to operational commanders to assign a dollar value or a dollar per diem rate for each equipment failure. The operational commander would be required to analyze the increased risks he runs by operating without his equipment and the effect of this loss on the Navy's mission or additional maintenance required by operating the equipment after failure of a component. Despite the inaccuracies inherent in such an estimation, this alternative offers the advantage of requiring the individual who best understands a cost difficult to measure to convert it to units commonly understood. The disadvantages of this alternative lie in the additional reporting requirement on the operational forces stands little chance of gaining approval.

A second alternative would be for an adhoc group of experienced operational commanders and economic analysts to classify various types of ship operating activity into categories which when matched with the ship's configuration produce a dollar value for each classification (C-2, C-3, C-4) of casualty. The classifying of operational activity for this purpose requires careful analysis. As noted in III-C, operating with casualties involves different risks. Casualties affect how a unit is operating and how it may plan to operate. The probable types of compensating actions that senior operational commanders might take would need to be accurately described and the results quantified.

An example of what would be achieved might be: an aircraft carrier operating in the Mediterranean during peacetime might be assigned a one-hundred dollar per day cost for each C-2 casualty reported. A forced draft blower casualty aboard this carrier would result in one-hundred dollars being charged to forced draft blowers for each day one was out of commission. The cost of all forced draft blower casualties so computed would be summed and this data used to predict a future cost which would determine the wisdom of an estimate of investment in performance improvement. The penalty per casualty would vary according to the level of local conflict, the class of ship, the season, the annual climatic conditions or other variables which the analyzing group deemed appropriate. Because the variations in operating conditions are infinite, establishing discrete categories would be a large part of the task.

A variant on this latter method would be to draw operational input from Delphi-type surveys and analysis. Either variant can be implemented without any additional workload for the operational forces.

A third alternative is possible which would require reporting by operational forces, but which might be palatable because it would not involve unit personnel themselves, but only the staffs of aggregate operational commanders. This alternative would require an operational commander to manipulate casualty reports submitted by its subordinate units and report a dollar cost for each. Instead of discrete categories of operational conditions, different variables governing operational conditions

could be evaluated by an operational commander and using a program devised for this purpose, these evaluations would determine the dollar cost. This alternative provides more flexibility with which to evaluate peculiar conditions than the second alternative, but less flexibility than the first. However, more investment is required by the third alternative in developing analytical techniques and more continuing dedicated effort that either of the first two alternatives.

E. Summary. None of these alternatives lessens the subjectivity in estimating operational readiness costs. Each alternative requires that judgement be exercised in comparing costs that are not commensurable. They all, however, shift the exercising of this judgement to individuals who are qualified on the basis of experience and training to measure and compare the costs involved. The first and third alternatives shift the comparison to individuals who are not only qualified but accountable for costs incurred by errors in this judgement.

The existing system best satisfies the dictum that equipment problems are solely the concern of the NMC. The degree of success NMC has had in solving these problems is to a great degree attributable to the cross-fertilization of personnel and ideas to and from those areas technically oriented and those operationally oriented.

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